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Glass-to-glass electrostatic bonding for FED tubeless packaging application

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Abstract

Two ITO-coated glass wafers (Corning #7740, #0080) are successfully bonded by the typical Si-Pyrex electrostatic bonding mechanism. Both Si-#7740 and Ti-(Li-doped SiO_2) interlayer systems can be employed for the electrostatic bonding of #7059–#7059 and #0080–#0080 glass wafer pairs. This glass-to-glass electrostatic bonding process can be applied to the clean and tubeless packaging of field emission display panels.

1. Introduction

The field emission display(FED) is one of the most promising flat panel displays, which uses micromachined Si or metal-tip array as cold cathode. As compared with other displays, it has many potential advantages such as, high color purity and resolution, wide viewing angle and operating temperature range, and compatibility with well-established IC process. The FED consists of cathode and anode plates having addressed micro-tip arrays and patterned low-voltage phosphors, respectively, and such two plates are finally combined by frit sealing and pump-out process in order to maintain the inner vacuum level of 10^{-7} torr [1,2].

If the final tube-based assembly process can be replaced by glass-to-glass bonding-based sealing as shown in Fig. 1, it will be possible to take some technical advantages. The panel thickness can be reduced to 2~3 mm by removing the 10~25 mm pump-out tube, and the out-gassing problems, which may occur during the tube seal-off process and also contaminate the inside of the panel, are avoidable. The chemical getter can also be installed at the final stage of vacuum bonding in the different way from the conventional FED vacuum packaging, and, therefore, some deterioration phenomena of getter property due to the high temperature frit treatment may be minimized.

In this work, a new glass-to-glass electrostatic bonding process was examined using metal–glass and Si–glass interlayers on the basis of conventional metal–glass electrostatic bonding mechanism. Two ITO-coated #7059 glasses with Si/#7740, interlayers, and two ITO-coated #0080 glasses with Ti/Li-doped SiO_2 interlayers were successfully bonded. Also the applicability of the glass-to-glass electrostatic bonding to FED tubeless packaging was investigated through the leak and long-term hermeticity test of glass-to-glass panels sealed by the electrostatic bonding.

2. Bonding mechanism

The glass-to-glass electrostatic bonding mechanism may be explained, as shown in Fig. 2, through the typical Si–Pyrex electrostatic bonding model [3–5]. The positive ion-containing glass materials were employed as interlayers for electrostatic bonding with Si or Ti interlayers, which have the mobile carriers and the similar thermal expansion coefficient (TEC) values comparable with the ones of glass interlayers.

At elevated temperature, the positive ions (Na^+, Li^+) in the glass become quite mobile and they are attracted to the negative electrode, that is, the glass–ITO interface. The more permanently bound negative ions in the glass are left, forming a space charge layer in both the glass and Si adjacent to the bonding interface. The resulting electric field between two interlayers may force them to be pulled into contact.

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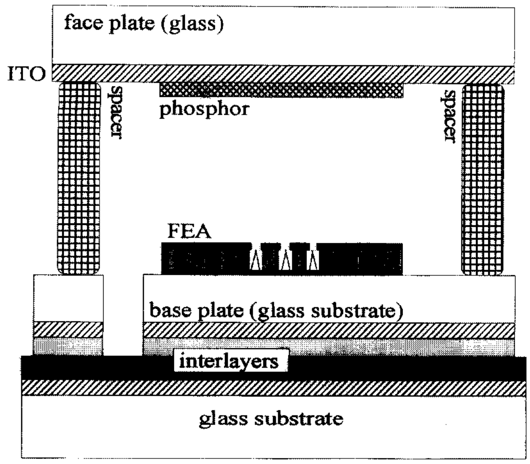

Fig. 1. Diagram of FED tubeless packaging based on electrostatic bonding in high vacuum.

3. Bonding of two ITO-coated #7059 glasses using Si-#7740 interlayers

3.1. Deposition of interlayer

The 1.1 mm-thick Corning #7059 glass wafers, on which 2000 Å-thick ITO (Indium Tin Oxide, R_s~20Ω/□) film was coated, were used as substrates. Si and #7740 interlayers were deposited by electron-beam evaporation on each ITO-coated #7059 glass substrate. The thickness of #7740 interlayers was fixed to a value of 1.5 μm, because it had been chosen previously as an optimum value considering surface roughness, Na concentration and width of space charge region. Table 1 shows the deposition parameters of Si interlayer by e-beam evaporation.

Fig. 3 shows the surface morphology of #7740 glass and Si films deposited on the ITO-coated #7059 glass substrates. In case of #7740 film, the peak-to-valley appeared to be almost the same (~249 Å) as that of ITO surface on the glass substrate. However, the peak-to-valley for Si film shows higher (~935 Å) than in case of #7740 film and this rough surface may cause the poor bonding. More improved film evaporation process might be needed in order to obtain smooth surface for Si film.

Fig. 4 shows the cross-sectional features of #7740 and Si films deposited on the ITO-coated #7059 substrate. While the deposited #7740 film has relatively smooth surface, the Si film has rough surface and some uncompleted film structure.

Table 1
Deposition condition of Si interlayer

Method	e-beam evaporation (model: Edward FL 400)
Evaporation source	Intrinsic Si chunk
Power	6000 W
Initial pressure	2×10^{-5} torr
Working pressure	5×10^{-5} torr
Substrate temperature	200°C
Deposition rate	1~10 Å/s
Thickness	0.4 μm

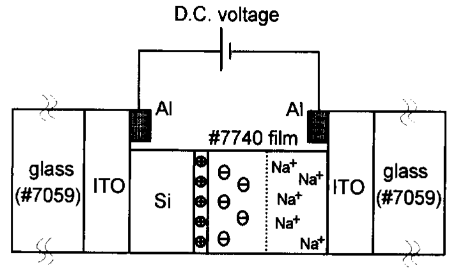

Fig. 2. Proposed mechanism of glass-to-glass electrostatic bonding using Si-#7740 interlayers.

3.2. Bonding process

As reported before [5,6], the electrostatic bonding apparatus consists of hot plate, voltage source–current recorder (Keithley SMU 237 model), and thermometer. The simplified diagram for glass-to-glass bonding is shown in Fig. 5. The anode and cathode are connected to the Si and #7740 films through ITO film, respectively. The optimal temperature and d.c. voltage ranges for electrostatic bonding seemed to be 200~00°C and 50~15 V, respectively, and the lowest temperature–voltage value appeared to be about 200°C–100 V.

After bonding, the bonded glass–glass wafer pairs were scribed with diamond cutter, and the sample cross-section was lapped/polished by sand paper/diamond powder/alumina powder. No separation or damage at the bonding interface occurred during the lapping and polishing process. The SEM cross-sectional view of the sample is shown in Fig. 6, and the small particles on the figure are due to the adhered alumina powder. Any non-bonded area and imperfections due to thermal or structural mismatch are not discovered under × 20 000 magnifications.

4. Bonding of two ITO-coated #0080 glasses using Ti-(Li-doped SiO_2) interlayers

A sodalime glass is very attractive as one of the glass substrates for FED panel from a view point of low cost, low permeation rate and compatibility with glass frits. In this experiment, two Corning #0080 (sodalime) glasses can be electrostatically bonded on the basis of the above-mentioned mechanism. Both Ti metal film and Li-doped SiO_2 films were selected as interlayers. The thermal expansion coefficient of Ti is about TCE~8.6 ppm/°C, and almost well matched with that of #0080 glass (TCE~9.25 ppm/°C). In case of Li-doped SiO_2 interlayer, Li ions play the same role in the oxide layer as Na ions in #7740 glass layers during the electrostatic bonding process. Also, the Li-doped SiO_2 interlayers have relatively higher dielectric breakdown field compared with the Na-contained #7740

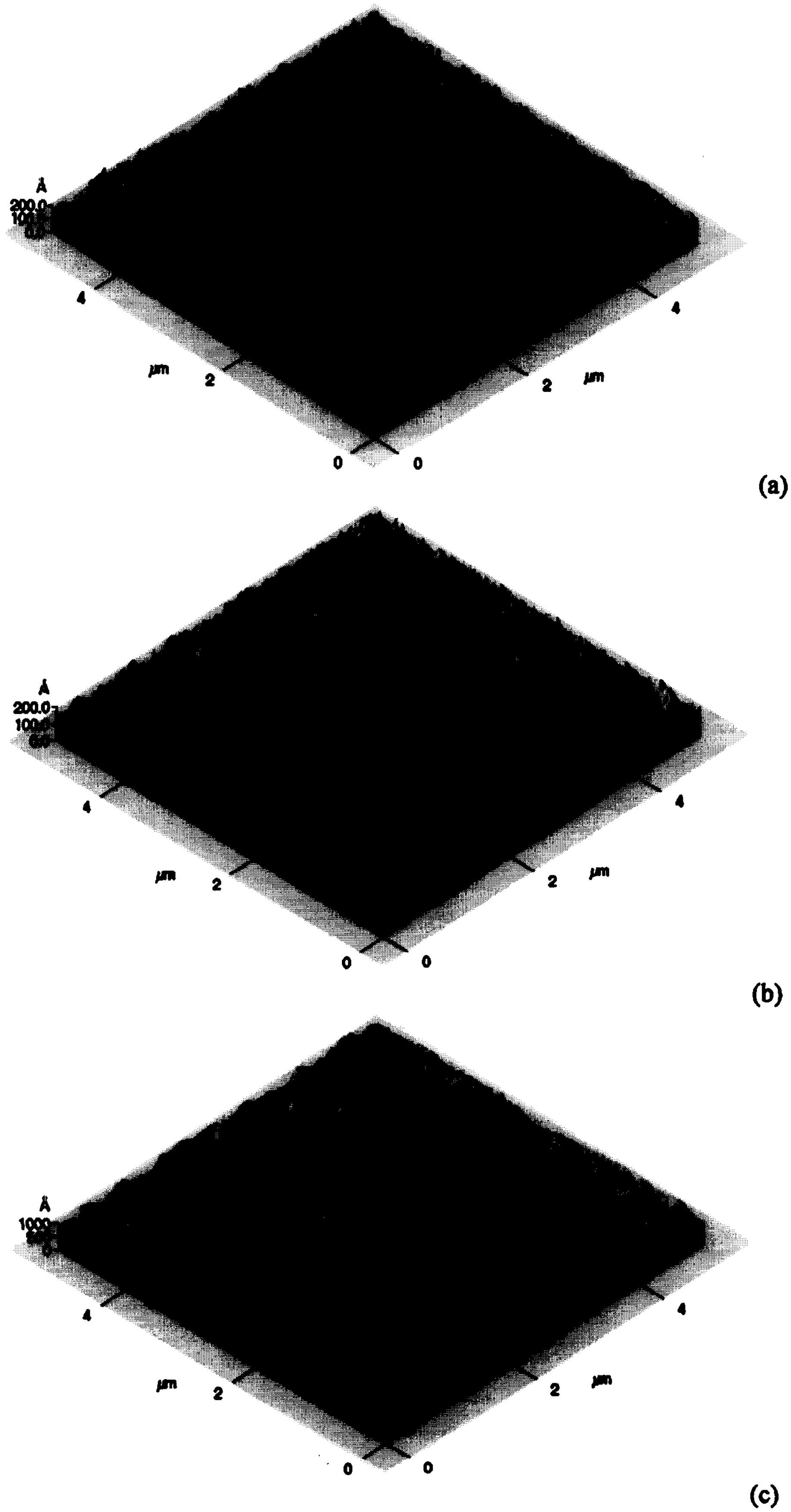

Fig. 3. Surface morphology measured by AFM. (a) ITO/#7059 substrate; (b) #7740 interlayer/ITO/#7059 substrate; (c) Si interlayer/ITO/#7059 substrate.

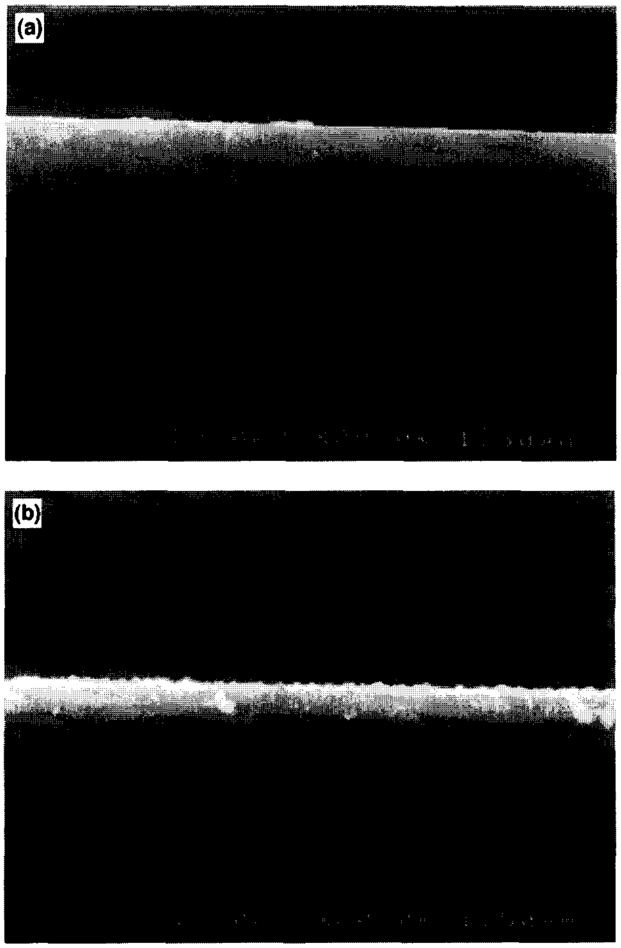

Fig. 4. SEM cross-sectional view of #7740 (a) and Si (b) thin films deposited on ITO/#7059 substrates.

layer, and the higher breakdown field is important for maintaining bonding stability. Moreover, the Li concentration as a key factor in bonding process can be controlled by changing the mixing rate of Li_2O and SiO_2.

As a substrate, 2000 Å-thick ITO (R_s~100 ⋙ /□) coated #0080 glasses (thickness~1.1 mm) were used, and Ti and Li-doped SiO_2 interlayers were deposited on each substrate. The deposition parameters are summarized in Table 2.

Electrostatic bonding of #0080 glass was performed in the same way as the one used for #7050 glass bonding.

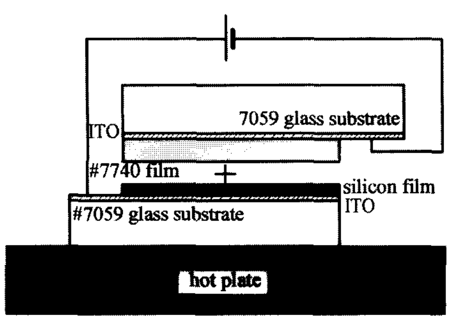

Fig. 5. Set-up for glass-to-glass electrostatic bonding using Si-#7740 interlayers.

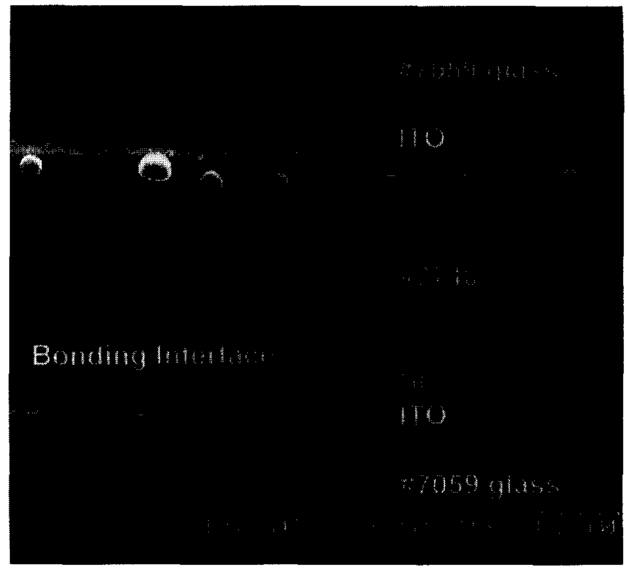

Fig. 6. SEM cross-sectional view of the bonded #7059/ITO/Si–#7740/ITO/#7059 structure.

The anode and cathode were connected to Ti and Li-doped SiO_2 layers through ITO film, respectively. The temperature and applied bias voltage ranges available for electrostatic bonding were set up to a value of 250~300 Å and 60~200 V, respectively. Fig. 7 shows SEM cross-sectional view of the bonding interface after lapping and polishing process. Some de-bonded areas were observed, as shown in Fig. 7(b), near the edge of the bonded wafer pairs, but they were less than 10% of whole area.

5. Applicability test for FED packaging

In order to evaluate the applicability of the glass-to-glass electrostatic bonding to FED tubeless packaging, the leak and long-term hermeticity tests of glass-to-glass panels sealed by the electrostatic bonding were performed under

Table 2
Optimum deposition conditions of Ti film and Li-doped SiO_2 film

Process parameters	Thin films for interlayers	
	Ti	Li-doped SiO_2
Method	Sputtering	e-beam evaporation
Source	Ti target (3 inch dia., 1/8 inch thick)	1.5 wt% LiO in SiO_2 powders (optimum surface roughness; 10 mm dia. pellet by mixing and pressing)
Power	4.7 W/cm^2	6000 W
Initial pressure	2×10^{-5} torr	2×10^{-5} torr
Working (gas) pressure	4×10^{-3} torr	5×10^{-5} torr
Substrate temperature	170°C	200°C
Deposition rate	200 Å/min	5 Å/s
Thickness	0.6~1.2 μm	1.5 μm

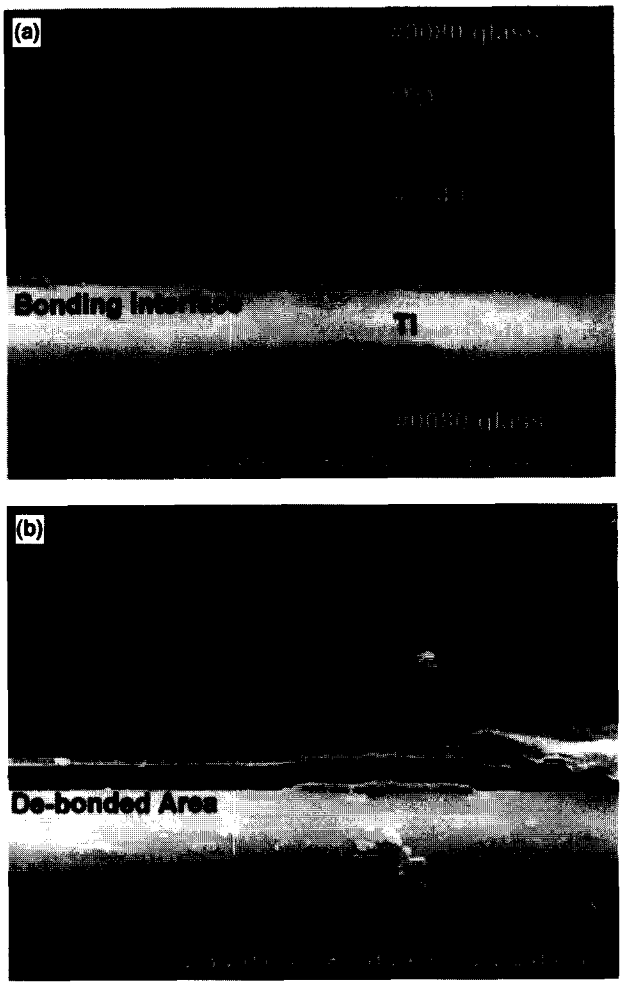

Fig. 7. SEM cross-sectional view of the bonded #0080/ITO/Ti–(Li-doped SiO_2)/ITO/#0080 wafer pair. (a) Bonded area; (b) de-bonded area.

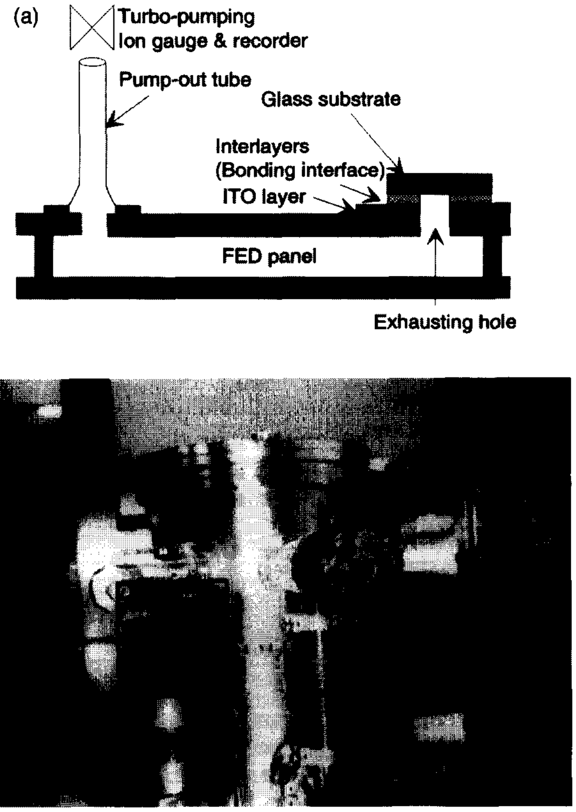

Fig. 8. Schematic diagram (a) and set up (b) of FED panel for leak and hermeticity test.

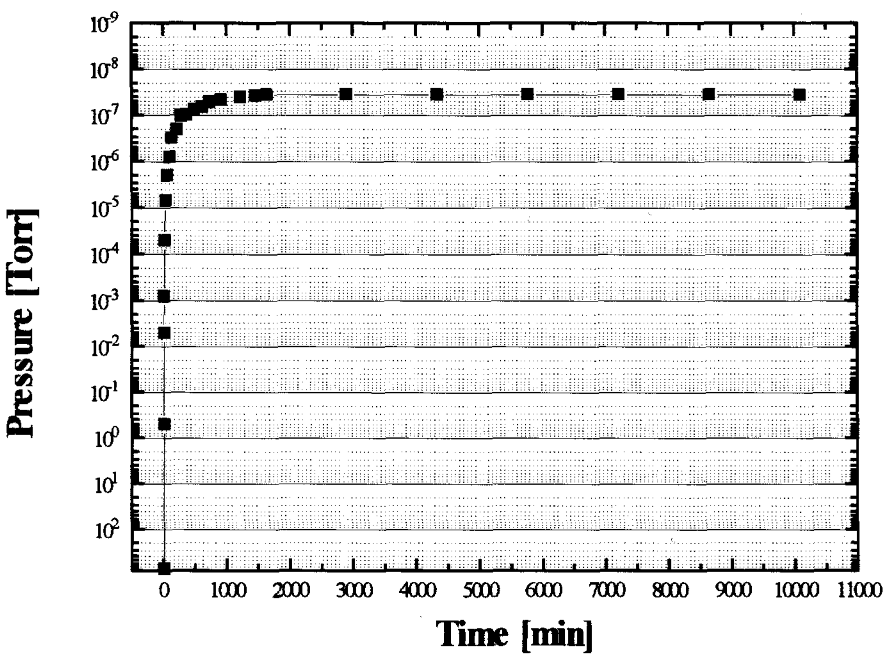

Fig. 9. Leak test result of FED panel sealed by glass-to-glass electrostatic bonding.

10^{-7} Torr vacuum level. Fig. 8(a) and (b) show the schematic diagram and photograph of FED panel structure prepared for leak and long term hermeticity test of glass-to-glass bonding interface. As shown in Fig. 8, the exhausting hole was sealed by glass-to-glass electrostatic bonding and the pump-out tube was connected to the turbo-pump. During pump-out process, the change of vacuum level in the FED panel and buffer chamber was detected by ion gauge.

Fig. 9 is a leak test result of the FED panel sealed by glass-to-glass electrostatic bonding. The vacuum level of inside panel was maintained with a value of 3×10^{-8} Torr after one week pumping and it has been confirmed that there is no leakage through the bonding interface between two bonded glass wafer pairs.

6. Conclusion

ITO-coated Corning #7059–#7059 and #0080–#0080 glass wafer pairs are successfully bonded by electrostatic bonding method by employing interlayers. As a result of our investigation about bonding interface structure and hermeticity, it has been found that this clean and simple glass-to-glass bonding technique can be applied effectively to the tubeless and high-performance packaging of FED and other related field emission devices

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